

QUALITY OF PACKED AND BIN STORED 'ANJOU' PEARS AS INFLUENCED BY STORAGE ATMOSPHERE AND TEMPERATURE

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ABSTRACT

Packed pears (Pyrus communis 'd' 'Anjou') were stored under four individual controlled atmosphere (CA) storage conditions (#1: CA of 1.5% O₂ and <1% CO₂ at -1.5C; #2: CA of 1.5% O₂ and <1% CO₂ at +1.5C; #3: CA of 1.5% O₂ and 3.0% CO₂ at -1.5C; #4: CA of 1.5% O₂ and 3.0% CO₂ at +1.5C). Loose pears in bins were stored under three CA storage conditions (#1: CA of 1.5% O₂ and <1% CO₂ at -1.5C; #2: CA of 1.5% O₂ and 3.0% CO₂ at -1.5C; #3: CA of 1.5% O₂ and 3.0% CO₂ at +1.5C). For packed pears, increased CO₂ in the storage atmosphere resulted in retention of peel color, reduced firmness loss and enhanced subjective scores, particularly for finish and stem condition. Pears stored loose in bins, prior to packing in late January in an atmosphere containing 3.0% CO₂ aided firmness retention, reduced scald and greatly enhanced subjective quality scores for appearance, finish and scuffing. Storing 'Anjou' pears in a 3.0% CO₂ atmosphere allows for storing pears loose in bin and packing in late January with little or no quality losses compared with using the standard 1.0% CO₂ in the storage atmosphere.

INTRODUCTION

The standard recommendation for long-term controlled atmosphere (CA) storage of 'Anjou' pears in the state of Washington is 1.0 to 2.0% O₂ and

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<0.5% CO₂ at -1 to -0.5C (Meheriuk 1993; Richardson and Kupferman 1999). Atmospheres of 2% to 2.5% O₂ and <1% CO₂ at -1C have also been recommended for CA storage of 'Anjou' pears (Hansen and Mellenthin 1979; Hardenburg *et al.* 1986; Richardson and Gerasopoulos 1994).

Using 2% or less O₂ for long-term storage reduced losses of firmness, acidity, greenness and reduced scald severity (Chen *et al.* 1981; Mellenthin *et al.* 1980; Chen and Varga 1999). Higher levels of CO₂ used in long-term storage of pears has been associated with internal breakdown, pithy brown core and other physiological storage disorders (Hansen and Mellenthin 1962; Chen and Varga 1999). Elevated levels of CO₂ (up to 3%) have been used for long-term pear storage (Allen and Claypool 1948; Drake 1994; Drake *et al.* 2001; Hansen 1956), but the quality following storage has been inconsistent and the storage industry has been reluctant to use this information. Pears are sensitive to elevated storage temperatures above the optimum (<1C) and no benefit of CA storage may be realized if this optimum temperature is not maintained (Richardson and Kupferman 1999). Storage of pears at temperatures above the optimum has resulted in loss of firmness, color, condition and excessive amounts of rot (Meheriuk 1988; Kupferman and Spots 1995). Other pome fruits have been stored in CA at temperatures above 1C with little or no loss of quality (Chen *et al.* 1989).

Removal of CO₂ to <1% and temperature reduction below 1C is a costly and time consuming operation (Waelti and Cavalieri 1990). CA pear storage research prior to 1990 was conducted with static systems where fruit are held in the same atmosphere over the entire storage period and commercial storage recommendations were based on this research. Most all new commercial CA storage facilities employ a flow-through system. Changes in atmospheres and temperature requirements with no losses in quality and storage cost reduction may be possible for the long-term storage of pears using the flow-through system. The research reported here was conducted to determine if 'Anjou' pears (packed or bin stored) could be held under conditions other than the recommended (elevated CO₂ and temperature) condition, packed late in the season (Jan/Feb) and still maintain fruit quality.

MATERIALS AND METHODS

During the first year of this study, in late September, three commercial pear storage facilities provided 48 packed boxes (24 boxes from each of 2 growers) of CA quality 'Anjou' pears, for a total of 144 boxes. One day after packing the pears were transported to the commercial CA research facility located at Sternilt Growers, Wenatchee, WA. Packed pears (24 boxes) from each grower were randomly divided into 4 storage treatments. Storage #1: CA of 1.5% O₂ and

<1% CO₂ at -1.5C; #2: CA of 1.5% O₂ and <1% CO₂ at +1.5C; #3: CA of 1.5% O₂ and 3.0% CO₂ at -1.5C; #4: CA of 1.5% O₂ and 3.0% CO₂ at +1.5C. The atmosphere in each room was established and maintained using a purge-type computer controlled CA system. A Servomix analyzer, model 1400B4 was used to determine atmosphere concentration and both atmosphere and temperature were monitored on a daily basis. After 90, 150 and 210 days, two boxes of pears from each grower were removed from each storage condition. One-half of the pears in a box were removed and quality evaluated on 20 pears immediately and on 20 pears after an additional 7 days at 20C. The remaining boxes (one from each grower and storage condition) were held in regular air (RA) storage (1.5C) for an additional 30 days to simulate shipping and handling time and were evaluated again as described. After quality was determined the remaining pears in each box were used to determine the amount of rot and scald.

During the second year of this study, 3 bins of CA quality 'Anjou' pears were obtained from four grower's (12 bins). Immediately after harvest the bins were transported to the commercial CA research facility. Bins of pears from each grower were divided into 3 storage treatments. #1: CA of 1.5% O₂ and <1% CO₂ at -1.5C; #2: CA of 1.5% O₂ and 3.0% CO₂ at -1.5C; #3: CA of 1.5% O₂ and 3.0% CO₂ at +1.5C. In late January the bins were removed from storage and pears commercially packed. After packing, 3 boxes from each grower and storage condition were transported to the USDA, ARS-TFRL and placed in RA storage. Packed pears were evaluated immediately (<1 week) after packing and after 30 and 60 days of storage as described.

Quality factors evaluated were firmness, external and internal color, soluble solids concentration (SSC), titratable acidity (TA), finish (appearance) and visual disorders (scald, shrivel, stem condition, internal breakdown and scuffing). Firmness, in newtons (N) was determined using the TA-XT2 Texture Analyzer (Texture Technologies, Scarsdale, NY) equipped with a 7.7 mm probe. External and internal color was determined with The Color Machine (Pacific Scientific, Silver Springs, MD) using the Hunter L*, a*, b* system and calculated hue° values (Hunter and Harold 1987). SSC and TA were determined from a composite of juice expressed from longitudinal slices from each of 20 fruit.

An Abbe type refractometer with a sucrose scale calibrated at 20C was used to determine SSC. TA was measured with a Radiometer titrator, model TTT85 (Radiometer, Copenhagen, Denmark). Acids were titrated to pH 8.2 with 0.1 N NaOH and expressed as percent malic acid. Finish and visual disorders (scald, shrivel, dark skin disorder and stem condition) of laboratory samples were determined by 17 to 24 individuals familiar with winter pear disorders and rated on a scale of 1 to 4 (1 = none; 4 = severe). Data were analyzed using SAS. Based on significant F tests means were separated using the Waller-Duncan test.

RESULTS AND DISCUSSION

Storage atmosphere and temperature has a major impact on the color of packed 'Anjou' pears, particularly peel color (Table 1). Pears stored in 3% CO₂ were darker (lower L* values) and greener (higher hue values) than pears stored in <1.0 CO₂ conditions. Lower storage temperature (-1.5C) resulted in darker greener pears. But, though differences in color were significant between the different conditions, the only economic difference was for pears stored in 1.5% O₂ and <1.0 CO₂ at 1.5C. Pears stored under these conditions were lighter in color (2 units) and less green or more yellow (3 units) than the pears stored at 1.5C under 3% CO₂ or -1.5C regardless of atmosphere. Differences in flesh color (L* values) were also present between pears from the different storage conditions, but these differences (<1.0 unit) would not be visible to the human eye (Hunter and Harold 1987).

Storage temperature and atmosphere also had a very direct influence on fruit firmness and the amount of rot and scald present in packed 'Anjou' pears. Pears stored in 3% CO₂ were firmer than pears stored in <1% CO₂, regardless of storage temperature. But, pears stored at 1.5C were less firm than pears stored at -1.5C when the atmosphere contained <1.0% CO₂. Use of 3% CO₂, regardless of storage temperature, helped to maintain packed fruit firmness during storage. Rot and scald, of 'Anjou' pears, have been associated with elevated CO₂ and temperature in the storage atmosphere. Elevated (1.5C) temperature and low CO₂ (<1.0) enhanced both rot and scald in packed 'Anjou' pears. Use of 3% CO₂ in the storage atmosphere and a storage temperature of 1.5C reduced rot and scald amounts comparable to pears stored at -1.5C regardless of the amount of CO₂ in the storage atmosphere. Previous studies (Drake 1994, 1999) have reported both reduced amounts of rot and scald in pears stored in 3% CO₂ with no enhanced internal discoloration.

Internal breakdown or enhanced darkening of the core was present in pears stored in 3% CO₂ in this study (Table 2) when compared with pears stored in 1% CO₂. But, 3% CO₂ had no influence on the amount of internal breakdown that would be considered noteworthy by fruit graders in the state of Washington (WAC 16-690). Discoloration to be considered must go beyond the core and in this study, even after 210 days of storage, no difference was noted between pears stored in either 1 or 3% CO₂. Industry concern of increased core discoloration of pears, as CO₂ with increases in the storage atmosphere is widespread and this does happen. But, even with increased core discoloration the reduction in storage cost with increased CO₂ in the storage atmosphere would be advantageous. There was slightly less (6.5% vs 10%) occurrence of core discoloration in pears stored at -1.5C vs +1.5C.

TABLE 1.
QUALITY ATTRIBUTES OF 'D'ANJOU' PEARS PACKED FOLLOWING HARVEST (SEPTEMBER) AS INFLUENCED BY STORAGE TIME,
RIPENING AND THE INTERACTION OF STORAGE TEMPERATURE AND ATMOSPHERE

	Peel Color		Flesh Color		Firmness (N)	Rot (%)	Scald (%)	
	L*	hue	L*	hue				
Temperature x Atmosphere								
-1.5C	1.0 % CO ₂	66.8b ^z	99.4b	79.9a	88.1a	32.7b	2.5b	1.4b
	3.0 % CO ₂	65.7c	100.7a	79.4a	88.1a	35.6a	1.5b	1.0b
+1.5C	1.0 % CO ₂	69.8a	95.9c	80.2as	87.9a	29.0c	6.5a	2.5a
	3.0 % CO ₂	67.4b	100.6a	80.7a	88.7a	34.8a	1.0b	1.1b
Storage Time (days)								
90		66.6b	100.9a	79.5b	88.1b	33.9a	0.8b	0.6b
150		68.3a	97.4b	80.6a	88.7a	32.2b	4.8a	6.1a
Ripe (days)								
0		64.9a	103.7a	80.1a	88.7a	55.5a	1.0b	0.05b
7		70.0b	94.6b	80.0a	87.7b	10.6b	4.5a	6.6a

^zMeans in a column, within groups, not followed by a common letter are significantly different ($P \leq 0.05$).

TABLE 2.
CORE DISCOLORATION OF SEPTEMBER PACKED 'ANJOU' PEARS AS INFLUENCED
BY STORAGE TEMPERATURE AND CONTROLLED ATMOSPHERE

Atmosphere	(% Core Discoloration ^z)		
	None	Core Only	Beyond Core
1.5% O ₂ & 1.0% CO ₂	95.0a	4.5b	0.5a
1.5% O ₂ & 3.0% CO ₂	88.5b	10.5a	1.0a
Temperature			
-1.5C	93.5a	6.0a	0.5a
+1.5C	90.0b	9.0a	1.0a
Atmos. × Temp.	ns	ns	ns

^z N = 40 pears.

^y Means within atmospheres or temperatures not followed by a common letter are significantly different ($P \leq 0.05$).

Both atmosphere and temperature had a strong influence on the subjective evaluation of packed pears (Table 3). Pears stored in an atmosphere of 3% CO₂ displayed superior appearance, finish, stem condition and reduced scald when compared with pears stored in 1% CO₂. In fact, the appearance (2.9) and finish (2.6) scores for pears stored in 1% CO₂ were not acceptable and exceeded what is considered an acceptable maximum score, 2.5. Differences in the scald rating of pears from the different atmospheres was slight, but present. Pears stored in 3% CO₂ were less prone to scald than pears stored in 1%. There was a considerable difference (0.4) in stem condition between pears from the two atmospheres. Many fruit buyers evaluate fresh fruit on stem condition alone. This difference in stem condition between the pears from the two atmospheres would make the pears stored in 3% CO₂ more valuable than pears stored in 1% CO₂.

Storage temperature influenced the subjective scores of packed pears, for appearance and finish. Regardless of storage temperature (-1.5 or +1.5C) scores for general appearance were marginal at best and were equal or exceeded what is considered a minimum score (2.5) after 210 days of storage. Even though pears stored at -1.5C received the best score (2.5 vs 2.7), the score was marginal. Scores for finish were also poor, but packed pears stored at -1.5C received a better score than pears stored at +1.5C. Subjective scores for scald, shrivel and stem condition were not influenced by storage temperature. The lack

of difference in scores for shrivel was not expected. It has long been postulated that higher storage temperatures would help to eliminate shrivel. In this study, no difference in shrivel was evident after storage regardless of the storage temperature.

TABLE 3.
SUBJECTIVE EVALUATION OF PACKED (OCTOBER) 'ANJOU' PEARS, AFTER
210 DAYS OF CONTROLLED ATMOSPHERE STORAGE AND FOUR DAYS OF
RIPENING, AS INFLUENCED BY STORAGE ATMOSPHERE AND
TEMPERATURE. (N=24)

	General Appearance ^z	Finish ^z	Scald ^z	Shrivel ^z	Stem Condition ^z
Atmosphere					
1.5 % O ₂ & 1.0 % CO ₂	2.9a ^y	2.6a	1.4a	1.3a	2.3a
1.5 % O ₂ & 3.0 % CO ₂	2.3b	2.3b	1.2b	1.3a	1.9b
Temperature					
-1.5C	2.5b	2.3b	1.3a	1.3a	2.2a
+1.5C	2.7a	2.5a	1.3a	1.3a	2.0a
Atmos. x Temp.	ns	ns	ns	ns	ns

^z Evaluated on a scale of 1 to 4 (1 = excellent/none, 2 = good/slight, 3 = fair/moderate, 4 = poor/severe).

^y Means within atmospheres or temperatures not followed by a common letter are significantly different $P \leq 0.05$.

Peel and flesh color of pears stored loose, in bins and packed in late January was influenced by storage temperature, atmosphere and ripening (Table 4). L* color values increased (lighter color) as ripening time advanced from 0 to 7 days for pears stored at -1.5C regardless of the amount of CO₂ in the atmosphere. L* color values did not change for pears stored at +1.5C as ripening time progressed. After 7 days, L* color values were similar for pears from the different storage conditions. Immediately after removal from storage hue values were similar regardless of storage condition. After ripening, hue values decreased (more yellow) at a similar rate for pears stored at -1.5C regardless of the amount of CO₂ in the storage. Pears stored at +1.5C were more yellow (lower hue values) after ripening than pears from the other storage conditions. Firmness was similar between pears, immediately after removal from

storage, regardless of CO₂ in the atmosphere or temperature. After ripening, pears stored in 3% CO₂ at -1.5C were firmer than pears from either other storage condition (1.0% CO₂ at -1.5C or 3% CO₂ at +1.5C).

TABLE 4.
COLOR AND FIRMNESS ATTRIBUTES OF LOOSE OR BIN STORED PEARS STORED UNDER 3 CONTROLLED ATMOSPHERE STORAGE CONDITIONS FOR 4 MONTHS, PACKED AND EVALUATED AFTER 0, 30 AND 60 DAYS ADDITIONAL REGULAR AIR (RA) STORAGE AS INFLUENCED BY THE INTERACTION OF STORAGE CONDITION AND RIPE

Storage Condition	Ripe (days)	Peel Color		Flesh Color		Firmness (N)
		L*	hue	L*	hue	
1.5 % O ₂ & 1.0 % CO ₂ at -1.5C	0	55.6b ^z	103.7a	67.9b	87.5a	52.6a
	7	60.0a	96.6b	73.7a	86.0b	9.2c
1.5 % O ₂ & 3.0 % CO ₂ at -1.5C	0	55.6b	103.3a	67.9b	87.3a	52.2a
	7	59.7a	97.1b	72.5a	85.5b	11.0b
1.5 % O ₂ & 3.0 % CO ₂ at +1.5C	0	58.6a	103.7a	64.9c	85.4b	52.5a
	7	60.1a	95.6c	72.6a	85.2b	9.2c

^zMeans in a column not followed by a common letter are significantly different ($P \leq 0.05$).

Core discoloration and scald of 'Anjou' pears was strongly influenced by atmosphere, temperature and time in storage (Table 5). Pears stored in 3% CO₂ at +1.5C were more prone to core discoloration than pears stored in 1.0 or 3.0% CO₂ at -1.5C. The amount of scoreable (beyond the core) core discoloration was particularly evident for pears stored in 3.0% CO₂ at +1.5C. Pears stored in 1.0 or 3.0% CO₂ at -1.5C displayed no scoreable core discoloration. Scald was very evident in pears stored in 1.0% CO₂ particularly when compared with pears stored in 3.0% CO₂, which displayed little or no scald. Time in storage resulted in both increased core discoloration and scald. Increased scoreable discoloration was only evident after the pears had been packed for 30 days; no discoloration was evident immediately after packing or after 60 days of storage. No scald was present immediately after packing or after 30 days of storage, but after 60 days 5.0% of the pears displayed scald.

TABLE 5.
DISORDERS OF LOOSE OR BIN STORED PEARS STORED UNDER 3 CONTROLLED
ATMOSPHERE STORAGE CONDITIONS FOR 4 MONTHS, PACKED AND EVALUATED
AFTER 0, 30 AND 60 DAYS ADDITIONAL REGULAR AIR (RA) STORAGE

Storage Condition	Core Discoloration (%)			Scald (%)
	None	Core only	Beyond Core	
1.5% O ₂ & 1.0 % CO ₂ at -1.5C	76.9a ^z	29.2a	0.0b	4.7a
1.5% O ₂ & 3.0 % CO ₂ at -1.5C	70.3ab	33.6a	0.0b	0.6b
1.5% O ₂ & 3.0 % CO ₂ at +1.5C	60.6b	23.1a	5.6a	0.0b
Storage time (days)				
0	65.3b	33.9a	0.6b	0.0b
30	64.2b	31.1a	4.7a	0.3b
60	78.3a	21.4b	0.3b	5.0a

^z Means in a column, within storage condition, or storage time not followed by a common letter are significantly different ($P \leq 0.05$).

Subjective scores for appearance, finish, scald and scuffing of pears stored in bins and packed in late January were influenced by storage atmosphere and temperature (Table 6). Scores for shrivel and stem condition were not affected by either storage atmosphere or temperature. Scores for appearance, scald and scuffing of pears stored in 1.5% O₂ and 3.0% CO₂ at -1.5C were superior to the scores received for pears stored in 1.5% O₂ and 1% CO₂ at -1.5C, which is considered the standard storage conditions for 'Anjou' pears in the state of Washington. Pears stored in 1.5% O₂ and 3.0% CO₂ at 1.5C received scores for appearance and finish that were equal to pears stored in 1.5% O₂ and 1.0% CO₂ at -1.5C. When the amount of scald and scuffing was considered, scores for pears in 3.0% CO₂ at 1.5C were superior to pears in 1.0% CO₂ at -1.5C. In this study, it was apparent that storage of pears in 3.0% CO₂ received subjective scores that were equal to or superior to pears stored in the standard 1.0% CO₂ atmosphere regardless of storage temperature. In addition, pears stored in 3.0% CO₂ can be stored loose in bins, packed in late January, stored for an additional 30 days in RA and receive acceptable subjective quality scores, particularly for scuffing. Late packed pears, stored in the standard atmosphere of 1.0% CO₂ have traditionally been prone to scuffing.

TABLE 6.
SUBJECTIVE EVALUATION OF BIN STORED, LOOSE 'ANJOU' PEARS IN CONTROLLED
ATMOSPHERE UNTIL JANUARY 15, COMMERCIAL PACKED, STORED FOR 30 DAYS IN
REGULAR AIR AND RIPENED FOR 4 DAYS AS INFLUENCED BY STORAGE
ATMOSPHERE AND TEMPERATURE. (N=17)

Atmosphere/ Temperature	General Appearance ^z	Finish ^z	Scald ^z	Shrivel ^z	Stem Condition ^z	Scuffing ^z
1.5% O ₂ & 1.0% CO ₂ at -1.5C	2.3a	2.0ab	1.3a	1.5a	1.8a	1.9a
1.5% O ₂ & 3.0% CO ₂ at -1.5C	1.8b	1.8b	1.0b	1.3a	1.5a	1.3b
1.5% O ₂ & 3.0% CO ₂ at +1.5C	2.2a	2.1a	1.0b	1.2a	1.6a	1.4b

^z Evaluated on a scale of 1 to 4 (1 = excellent/none, 2 = good/slight, 3 = fair/moderate, 4 = poor/severe).

^y Means in a column not followed by a common letter are significantly different ($P \leq 0.05$).

CONCLUSIONS

The standard atmosphere and temperature for the storage of 'Anjou' pears in Washington State is 1.5% O₂ and 1.0% or less CO₂ at -1.5C. In this study, pears stored 1.5% O₂ and 3.0% CO₂ at -1.5C displayed superior quality when packed immediately after harvest and stored for 210 days, or stored loose for 4 months prior to packing. Increased CO₂ in the storage atmosphere, for packed pears, resulted in retention of peel color, reduced firmness loss and enhanced subjective scores, particularly for finish and stem condition. Pears stored loose in bins, prior to packing in late January in an atmosphere containing 3.0% CO₂ aided firmness retention, reduced scald and greatly enhanced subjective quality scores for appearance, finish and scuffing. Storing 'Anjou' pears in a 3.0% CO₂ atmosphere allows for storing pears loose in bin and packing in late January with little or no quality losses compared with using the standard of 1.0% CO₂ in the storage atmosphere.

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